

An observational study exploring amplitude-integrated electroencephalogram and Spectral Edge Frequency during paediatric anaesthesia

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SUMMARY

Processed electroencephalography is used in adults to guide anaesthesia, but the algorithms used may not apply to infants. Knowledge of infants' electroencephalogram (EEG) responses to anaesthetics is fragmentary. An earlier pilot study suggested amplitude-integrated EEG (aEEG) may be a useful measure of anaesthetic effect. The aim of this study was to determine how aEEG changes between awake and anaesthetised children of varying ages and to compare the response to that seen with Spectral Edge Frequency 90% (SEF90). A prospective observational study of children receiving a general anaesthetic was conducted. Anaesthetic regimen remained at the discretion of the treating anaesthetist. EEG data were collected using the BrainZ ReBrim™ monitor using forehead and biparietal montages. SEF90 and aEEG were compared across age groups, EEG montage and between awake and anaesthetised states.

A total of 178 children (aged 24 days to 14 years) were recruited. All aEEGs were greater during anaesthesia compared to when awake and this difference varied with age. Only children older than two years showed lower SEF90 while anaesthetised compared to when awake. SEF90 from children younger than six months was higher during anaesthesia compared to when awake. Analysis of parietal and forehead EEG montages revealed age-related differences. These findings suggest that SEF90 and aEEG can discriminate between awake and anaesthetised states in older children. In younger children aEEG changes are less pronounced and SEF90 either cannot discriminate between states or responds paradoxically. The aEEG may be marginally better than other EEG parameters in measuring anaesthetic depth in children.

Key Words: brain, monitoring, anaesthesia, age factors

In adults, the use of processed electroencephalogram (EEG) depth monitors, such as the Bispectral Index® (Covidien Inc., Boulder, CO, USA) and Entropy® (GE Healthcare, Buckinghamshire, UK), have been shown in some studies to be associated with a reduction in anaesthetic consumption, recovery times and postoperative nausea and vomiting^{1,2}. However, the effect of their use on the incidence of intraoperative awareness remains controversial³⁻⁵. It is less clear if the currently available depth of anaesthesia monitors offer benefits in the paediatric population⁶. Studies attempting to validate these devices in children

have shown that in older children they usually have performance characteristics similar to adults, but in children younger than two years of age there is increasing evidence that the monitors do not behave as they do in adults or older children⁶⁻¹¹. These findings are not surprising considering the developmental changes that occur in the EEG with increasing age^{12,13}, such as the gradual increase in dominant awake frequency with age¹⁴. This change in dominant frequency would be expected to be particularly relevant to processed EEG parameters that use the frequency domain.

The amplitude-integrated electroencephalogram (aEEG) is a digitised version of the Cerebral Function Monitor developed by Maynard and colleagues¹⁵. As a time domain parameter, aEEG analysis involves EEG information being subjected to an envelope detection algorithm. This time compression method permits assessment of EEG amplitude changes¹⁶. Initially used to monitor critically ill adults¹⁵, the Cerebral Function Monitor

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has also been shown to detect anaesthetic-induced changes in adults¹⁷. More recently, the aEEG has been adopted into neonatal practice¹⁶ for seizure detection¹⁸ and long-term monitoring after hypoxic ischaemic events^{19,20}.

Unlike the aEEG, which uses the time domain of the EEG, the Spectral Edge Frequency (SEF) assesses EEG in the frequency domain. SEF is the frequency in an epoch of EEG data below which a set percentage of the EEG power spectrum is contained. Investigations of SEF during anaesthesia in the adult population have demonstrated consistent changes²¹.

A previous pilot study in infants²², found that while there were no changes with emergence from anaesthesia in the SEF 90% (SEF90), there was a suggestion that changes did occur in the aEEG. This study was limited, however, by its small sample size, only short periods of artefact-free recording and very little recording of participants in the completely awake state. Hence, further examination of the aEEG and SEF90 parameters was required. We decided that more evidence that aEEG does respond to anaesthesia in an observational setting is required before performing the more technically and ethically challenging studies to determine dose responses in children's aEEG and SEF90 under controlled anaesthetic conditions. Thus, the aim of this prospective observational study was to investigate, in a number of different age groups, the changes in aEEG between awake and anaesthetised states and compare these to changes in SEF90. A secondary aim was to examine potential EEG differences according to hemispheric location.

MATERIALS AND METHODS

The study was approved by the Royal Children's Hospital Human Research Ethics Committee (Reference 28116A). Due to the exploratory nature of this observational study no power calculation was undertaken prior to recruitment. Pragmatically, the number of children chosen was the number that was expected to be enrolled within one year. As the younger brain develops at a more rapid rate, recruitment of children was stratified into six age groups and skewed toward younger children. The six age groups were: one day to six months, six to 12 months, one to two years, two to four years, four to eight years and eight to 14 years. Inclusion criteria were all children scheduled for general anaesthesia. However, children were excluded if they had a known neurological condition or if the sensors would interfere with procedures such as facial surgery or magnetic resonance imaging.

Informed, written consent was obtained from a parent of the child. Then if time and the child would allow, EEG sensors were placed prior to induction of anaesthesia. If this caused distress to the child, the sensors were placed once the child was anaesthetised. Sensor sites were C₃, C₄, P₃, P₄, and F_{p1} and F_{p2} according to the international 10–20 system²³, and a reference electrode behind an ear. BrainZ™ Hydrogel Sensors (Natus Medical Incorporated, San Carlos, CA, USA) were applied to the scalp after exfoliation of the site and application of a small amount of conductive paste. Sensors remained in situ until the child was awake and about to leave the post anaesthesia care unit.

During this observational study, the choice of anaesthetic was at the discretion of the treating anaesthetist. Signal quality data and raw EEG were visible only to research staff for the duration of the anaesthetic. (Anaesthetic staff did not have access to the EEG information as the monitor was turned away from their line of view.) Processed EEG parameters were not available until later analysis. Collected demographic and perioperative data included age of the child, procedure, any pre-existing medical illness, any regular medication and use of sedative premedication. Once EEG recording had commenced, the EEG tracings were directly annotated. Relevant marked points included onset of anaesthesia, insertion of airway and awakening.

SEF90 is obtained by subjecting raw EEG to a spectral analysis using a Fast Fourier Transform. In a given epoch the SEF90 is the highest frequency (Hz) at which 90% of the power spectrum is contained²⁴. Generating aEEG involves raw EEG being passed through an asymmetric filter²⁵. The filtered signal is then rectified to convert the negative portion of the EEG signal to positive²⁶. Utilising an envelope detection method, the rectified signal is passed through a circuit that follows the input peaks as they rise in amplitude²⁷. This provides the maximum aEEG parameter. Once at the top of the peak, the trace exponentially decays until there is another peak in the rectified EEG. The decay rate and the distance between EEG peaks determine the minimum aEEG²⁶. Within the frequency range 2 to 20 Hz the ReBrim™ monitor (BrainZ Instruments Limited, Auckland, New Zealand) calculates the aEEG and SEF90 from four second epochs²⁸.

EEG data were analysed offline following conversion to BrainZ Rescue Monitor™ format using File Converter version 1.03 (BrainZ Instruments Limited, Auckland, New Zealand). Once in BrainZ

Rescue Monitor format, files were reviewed using AnalyzeResearch 1.7 (BrainZ Instruments Limited, Auckland, New Zealand). SEF90, maximum and minimum aEEG, Mains Hum (HUM), Impedance (IMP) and electromyography (EMG) values along with event marks contained in one minute epochs were then exported to Microsoft® Excel 2002 (Microsoft Corporation, Washington, USA). Combined data was then imported into Matlab® Version 7.7.0 (R2008b) (The MathWorks™, Inc. Natick, MA, USA) for filtering and analysis. Filtering consisted of removing periods of high IMP, HUM and EMG artefact. A bespoke Matlab program was used to identify EEG data with periods of $IMP > 10 \text{ k}\Omega$, $HUM > 50 \mu\text{Vpp}$ and $EMG > 10 \mu\text{V}^2$. Once a period of excessive artefact was identified this line of EEG data was removed. In addition, to reduce the impact of interference on adjacent lines of data, the program also removed the minute before and after. This filtering removed contamination with artefact such as electrocautery and movement.

EEG parameters were analysed when children were 'awake' and 'during anaesthesia'. To obtain the 'during anaesthesia' EEG data, a Matlab program was written that examined the availability of individual patient's EEG data 10 minutes after the establishment of the artificial airway. If this portion of data had been removed, due to excessive artefact, the program then searched, at increasing minutes, for usable data until the time of airway removal. The presence of anaesthetic stability or surgical stimuli was not ascertained.

To identify suitable 'awake' EEG data, the filtered EEG parameters were plotted against time for individual patient files. These revealed periods of post-filtered EEG available for analysis. The raw EEG was then visually inspected, around the identified timepoint, to identify one minute of suitable data. The data was rejected if it had excessive artefact, events marks indicating atypical activity such as the patient touching the sensors, or indicating the patient was asleep.

STATISTICAL ANALYSIS

Analysis of children's data was undertaken overall and within their six predefined age groups. Statistical software package STATA®, Release 11.0 (STATA Corporation, College station, Texas, USA) was utilised for the statistical analysis. Assessment of awake and anaesthetised EEG data was made on one minute epochs.

Assessment of the influence of montage on aEEG and SEF90 recordings comparisons of F_{p1} - F_{p2}

(forehead), C_3 - P_3 (left) and C_4 - P_4 (right) montages were made using a non-paired Student's t-test. A Student's t-test was also conducted on the age-grouped data.

To identify the correlation coefficient between EEG parameters and age, a linear regression analysis was used. This analysis was applied on values obtained while awake and during anaesthesia. Initially regression analysis was conducted on all age groups then post hoc on children under and over two years of age.

EEG parameters obtained during awake and anaesthesia for the different ages were compared with a non-paired Student's t-test. The influence of age and timepoint was analysed using a two-way analysis of variance. Throughout the analyses a P value of < 0.05 was considered statistically significant.

RESULTS

A total of 213 families were approached to participate in the study. Of those approached 33 (15%) declined to take part. Post-consent, two children were not included in the analysis. The first of these was excluded as the patient's procedure was cancelled due to an emerging viral illness with associated pyrexia. The second child, once the EEG sensors were applied, was noted to have a marked reduction in the amplitude from the right hemisphere. This child was subsequently investigated and found to have had a previously undiagnosed intra-uterine stroke.

The remaining 178 children ranged in age from 24 days to 14 years and further demographic details are contained in Table 1.

Across the groups there were a larger proportion of males (67%) than females (33%). The types of procedures varied according to age. There was a higher incidence of gastrointestinal endoscopies and orthopaedic procedures in older children. Younger children underwent more hernia repairs, intra-abdominal surgery, genital surgery or cystoscopies.

Children received a range of medications and anaesthetic agents. Premedication varied according to clinical requirements. Across the ages premedication with midazolam was unevenly distributed. More children aged between two and eight years received midazolam premedication. There was an even distribution of inhaled anaesthetic usage across age groups, but there was a higher use of propofol in the older age groups.

With reducing artefact tolerances there was a corresponding loss of data available for analysis. The previously reported tolerances of $IMP > 10 \text{ k}\Omega$,

HUM $>50 \mu\text{Vpp}$ and EMG $>10 \mu\text{V}^{22}$ demonstrated an acceptable preservation of data.

EEG recordings obtained while the children's breathing was maintained with an artificial airway had a median duration of 33 minutes (range 6 to 153 minutes). Total anaesthetised samples used were forehead $n=118$, and parietal $n=122$. Given the varied time duration of the procedures the post filtered data available for analysis reduced with time. Utilisation of the timepoint 10 minutes after the establishment of the artificial airway to start to retrieve data for subsequent analysis corresponded with peak availability of post filtered data. Thus, a majority of the data was obtained from this

10 minute timepoint (forehead 110 samples and parietal 106 samples).

Hemispheric comparisons of EEG parameters when awake and anaesthetised

SEF90 and aEEG values obtained from left and right hemispheres during anaesthesia or awake for all age groups showed no significant difference between left and right montages ($P > 0.4$). Subsequently, the mean of the left and right EEG data was used for analysis as a parietal value.

When aEEG values from all children were analysed, whether awake or anaesthetised, those obtained from the forehead montage were lower

TABLE 1
Participant demographic data

	<6 months n=29	6-12 months n=30	1-2 y n=29	2-4 y n=31	4-8 y n=30	8-14 y n=29	Total
Age in days, mean (SD)	89 (± 43.9)	261 (± 48.2)	502 (± 109.2)	1048 (± 190.1)	2139 (± 423.8)	3843 (± 596.6)	—
Gender, M/F	22/7	23/7	19/10	22/9	19/11	14/15	—
<i>Procedure</i>							
Gastrointestinal endoscopy	—	1	2	5	2	8	18
Penile/genital surgery/cystoscopy	6	14	8	10	3	6	47
Hernia repair	9	—	1	6	6	1	23
Orthopaedic	1	2	1	1	4	9	18
Plastic surgery	4	7	7	3	2	1	24
Ophthalmic	—	3	2	2	4	—	11
ENT	1	2	6	3	6	4	22
Intra-abdominal surgery	8	1	2	—	2	—	13
Bone marrow harvest	—	—	—	1	1	—	2
Midazolam premedication	—	2	4	8	8	1	—
<i>Anaesthetic variables</i>							
Propofol	4	2	2	5	12	15	—
N ₂ O	22	30	28	30	29	27	—
Airway: facemask/LMA/ETT	4/7/18	0/14/16†	2/12/15	1/25/5†	3/18/9†	0/24/5	—
<i>Inhaled anaesthetics</i>							
Sevo only	12	8	9	9	7	9	—
Iso only	1	—	1	1	2	3	—
Sevo to Iso	14	21	16	21	21	15	—
Sevo to Iso to Sevo	2	1	3	—	—	2	—
Opioids	7	9	10	8	13	13	—
Neuromuscular blockage	8	3	1	—	3	0	—
<i>Blocks</i>							
Caudal/femoral/nerve/umbilical	13/0/1/0	12/0/1/0	9/1/1/0	10/2/0/2‡	5/2/0/0	3/5/1/0	—

SD=standard deviation, M=male, F=female, ENT=ear, nose and throat, N₂O=nitrous oxide, LMA=laryngeal mask airway, ETT=endotracheal tube, Sevo=sevoflurane, Iso=isoflurane. † One child had an LMA inserted then required an ETT. ‡ One child required a caudal and a femoral block.

than those from the parietal area ($P < 0.0001$) (anaesthetised values shown in Table 2). SEF90 showed no statistically significant difference in awake values obtained from the forehead compared to the parietal montage (mean difference = 0.9 Hz; $P = 0.15$), but forehead values were higher than

parietal during anaesthesia (mean difference = 2.0 Hz; $P < 0.001$).

Between forehead and parietal montages, in different age groups, there was insufficient forehead awake EEG data to perform a non-paired t-test on children aged six months to one year and eight

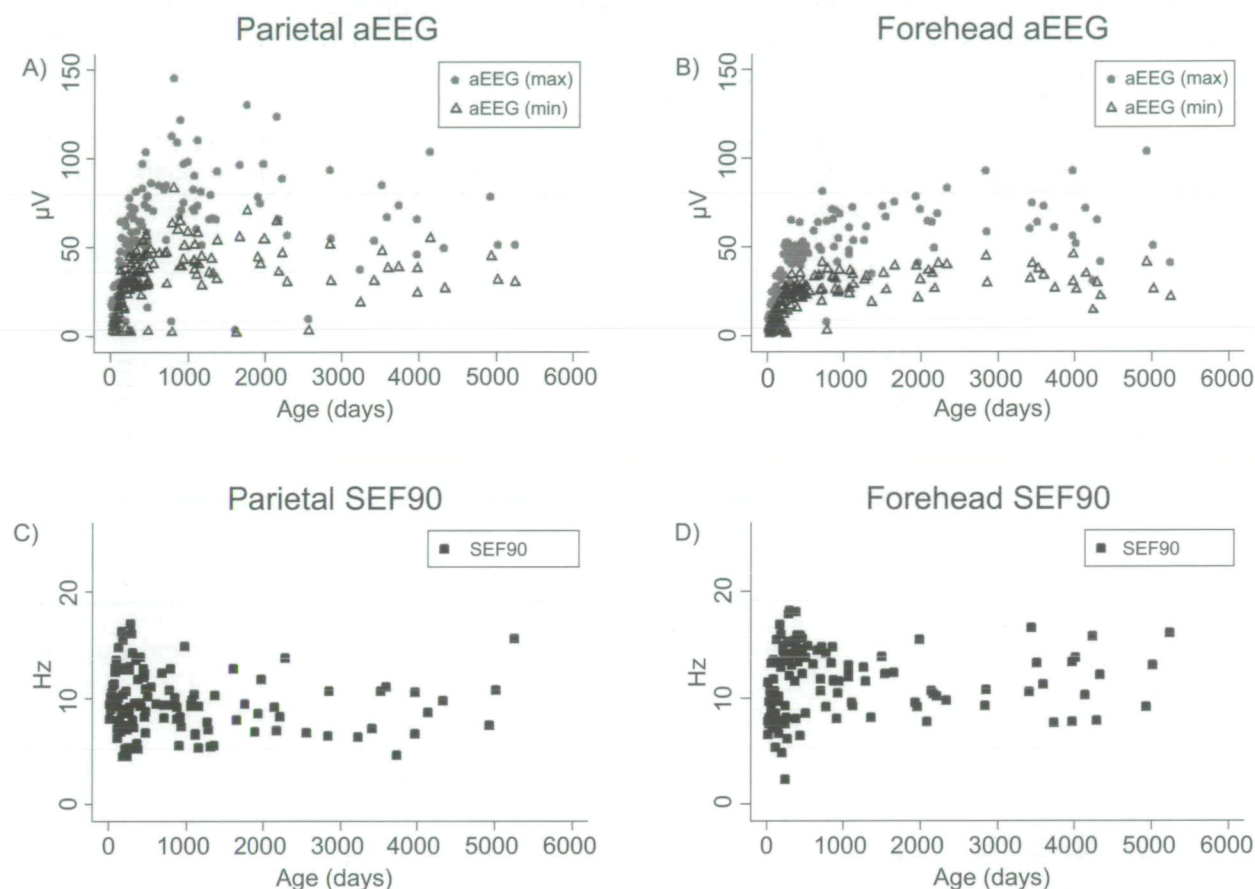


FIGURE 1: Scatter plots of amplitude-integrated electroencephalogram (aEEG) and Spectral Edge Frequency 90% (SEF90) versus age during anaesthesia (parietal $n=122$ and forehead $n=118$).

TABLE 2

Spectral Edge Frequency 90% and amplitude-integrated electroencephalogram comparisons of forehead to parietal recordings during anaesthesia

Age group	aEEG maximum		aEEG minimum		SEF90	
	Mean difference, μV	P value	Mean difference, μV	P value	Mean difference, Hz	P value
All children	-16.9	<0.0001	-10.4	<0.0001	2.0	<0.0001
<6 months	-14.2	0.0001	-6.9	0.0013	-0.3	0.6336
6-12 months	-17.5	0.001	-10.6	0.0003	2.5	0.0275
1-2 y	-19.9	0.0002	-11.1	0.0004	3.3	0.0001
2-4 y	-27.6	0.0006	-16.7	0.0003	2.7	0.0004
4-8 y	-6.6	0.5567	-6.5	0.2968	1.7	0.0646
8-14 y	-1.1	0.8868	-4.6	0.2098	2.8	0.0225

Students t-test differences are forehead minus parietal. aEEG=amplitude-integrated electroencephalogram, SEF90=Spectral Edge Frequency 90%.

to 14 years. While anaesthetised, the difference between the parietal and forehead aEEG of children changed with increasing age, as shown in Table 2. Children younger than four years demonstrated higher aEEG values from the parietal compared to forehead montages ($P < 0.05$). Children over four years of age showed no statistically significant difference.

During anaesthesia there was no difference in SEF90 obtained from forehead compared to parietal montages in children less than six months of age ($P=0.6$). In children older than six months the SEF90 obtained from the forehead montage was higher than the parietal recordings, as detailed in Table 2.

Changes in aEEG and SEF90 during anaesthesia related to age

When the aEEG of all children was examined there was a low correlation with increasing age from the parietal montage ($r^2=0.06$, $P < 0.0065$) whereas the forehead montage demonstrated a moderate degree of correlation with age ($r^2=0.3$, $P < 0.00001$),

shown in Figures 1A and B. Visual inspection of the dot plots, of children's age compared to aEEG, indicated a possible age-related change at approximately two years of age, shown in Figures 1A and B. Thus a post hoc piecewise analysis was performed on children over and under two years of age. From children below two years of age there was a consistently higher degree of correlation between age and aEEG in the parietal aEEG (aEEG maximum $r^2=0.45$, $P < 0.00001$; aEEG minimum $r^2=0.44$, $P < 0.00001$) and forehead aEEG ($r^2=0.6$, $P < 0.00001$). Of children older than two years of age, there was no correlation between age and aEEG (parietal aEEG maximum $r^2=0.08$, $P=0.053$, $P=0.062$; aEEG minimum $r^2=0.07$, $P=0.071$) and all forehead aEEG ($r^2 < 0.03$, $P > 0.3$).

There was a low correlation between age and SEF90 from forehead ($r^2=0.0015$, $P=0.6$) or parietal ($r^2=0.008$, $P=0.34$) montages, as shown in Figure 1C and D. In children younger than two years of age the correlation between SEF90 and age for the parietal montages remained low ($r^2=0.0009$, $P=0.8$), while there was an increased degree of correlation

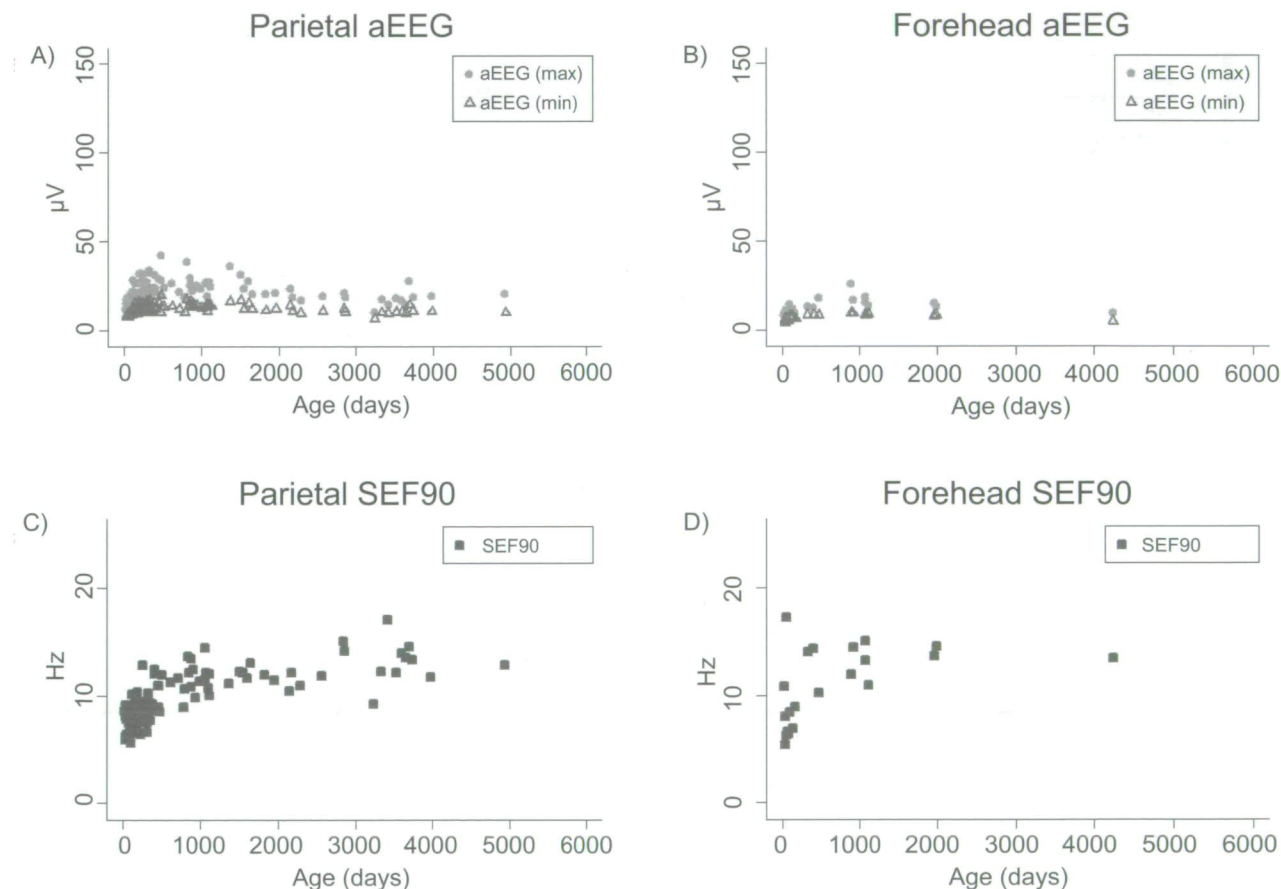


FIGURE 2: Scatter plots of amplitude-integrated electroencephalogram (aEEG) and Spectral Edge Frequency 90% (SEF90) versus age while awake (parietal $n=93$ and forehead $n=21$).

between SEF90 and age in the forehead montage ($r^2=0.17$, $P=0.0003$).

Changes in aEEG and SEF90 while awake according to age

EEG sensors were applied pre-anaesthesia to 168 children. These recordings had a median duration of 48 minutes (range 4 to 330 minutes). Awake recordings showed a large amount of contamination from artefact such as electromyogram, blinking and movement. This was particularly evident in forehead regions with only 21 (13%) awake data points available for analysis. From the parietal

recordings there were 93 (55%) useable awake data points.

Overall, aEEG from awake children showed a poor degree of correlation with age in the forehead ($r^2 < 0.02$, $P > 0.4$) and parietal ($r^2 < 0.03$, $P > 0.1$) montages as shown in Figure 2A and B. When the children younger than two years of age were analysed independently there was a consistently higher degree of correlation between aEEG parameter and age in the forehead ($r^2 > 0.3$, $P < 0.04$) and parietal ($r^2 > 0.28$, $P < 0.0001$) aEEG values.

SEF90 of all children showed a moderate to large degree of correlation with age in the samples taken

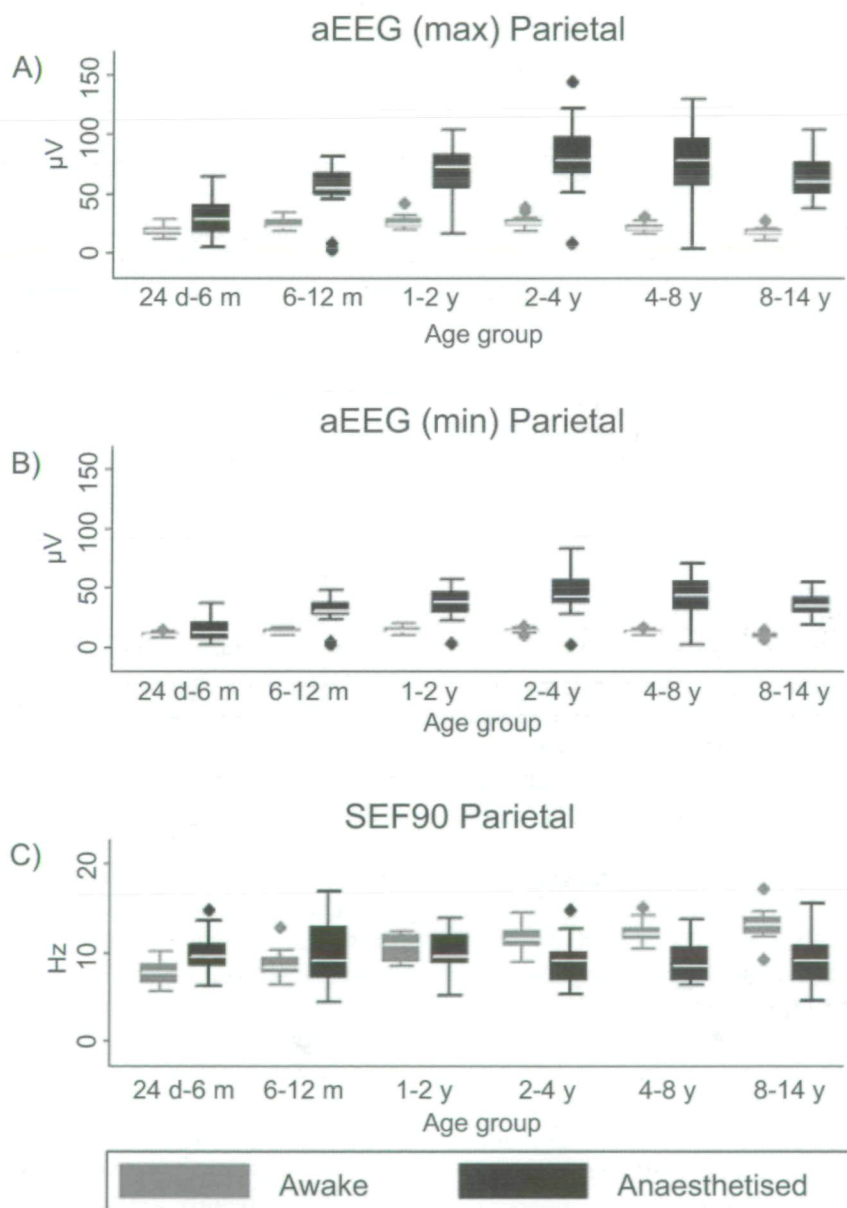


FIGURE 3: Box-and-whisker diagrams showing the parietal amplitude-integrated electroencephalogram (aEEG) and Spectral Edge Frequency 90% (SEF90) at awake and anaesthetised according to age group.

from parietal montages ($r^2=0.5$, $P < 0.0001$), as shown in Figure 2C. Awake SEF90 median values of age grouped data also increased with age, shown in Figure 3C. There was a weak correlation with age from forehead montage ($r^2=0.2$, $P=0.03$), as shown in Figure 2D. When the children younger than two years of age were analysed independently, similar correlations to the 'all children' analysis were seen with only a slight reduction in the degree of correlation of SEF90 with age in the parietal montages ($r^2=0.4$, $P < 0.0001$) and little change in the forehead values ($r^2=0.2$, $P=0.14$).

Differences in aEEG and SEF90 between awake and anaesthetised

From all children parietal aEEG values were higher during anaesthesia compared to awake values. While parietal SEF90 demonstrated no significant difference between awake and anaesthetised values (mean difference -0.6 Hz, $P=0.099$). Once grouped into their prospectively defined six age groups, the parietal aEEG values were usually higher in anaesthetised compared to awake states, as seen in Figure 3A and B. Mean differences between the states of awake and anaesthetised aEEG recordings differed according to age group. Children younger than six months of age demonstrated the smallest difference between states. There was not a statistically significant difference between awake and anaesthetised, parietal aEEG minimum, of children aged less than six months (mean difference $3.7 \mu\text{V}$, $P=0.063$). Between children aged younger than six months to children aged between two to four years the aEEG mean difference, between awake and anaesthetised values, increased with increasing age. Children aged between two to four years and four to eight years showed similar aEEG mean differences between awake and anaesthetised values. While children aged between eight to 12 years of age demonstrated lower aEEG mean differences between awake and anaesthetised values, these were similar to those obtained from children aged between one to two years of age.

A lack of available forehead EEG data limited the analysis between forehead awake and anaesthetised states for the age groups between 6 to 12 months and 8 to 14 years of age. In the remaining age groups, the forehead aEEG recordings in children younger than six months of age showed no evidence for a difference between awake and anaesthetised states. In the older age groups an increasing mean difference was observed.

Parietal SEF90 from children older than two years of age was lower during the anaesthetised state

compared to the awake state as shown in Figure 3C. Conversely, in children younger than six months of age, parietal SEF90 was higher in the anaesthetised compared to awake state (mean difference 2.1 Hz, $P=0.0002$).

The two-way analysis of variance for all parameters demonstrated evidence for an interaction ($P < 0.001$) between state (anaesthetised and awake) and age group; the effect of state depending on the age group.

DISCUSSION

This exploratory observational study investigated aEEG and SEF90 changes occurring in 178 children while receiving an anaesthetic according to the anaesthetist's discretion. The main findings were that aEEG and SEF90 parameters of children change according anaesthetic state. However, these changes with anaesthetic are age-related. In addition, aEEG and SEF90 parameters obtained from frontal montages compared to parietal locations, also demonstrated changes with age.

During anaesthesia the absolute magnitude of aEEG increases with age to those of around two years of age. For those older than two years of age, aEEG demonstrated little in the way of age-associated changes. In the awake state aEEG also increased in magnitude with age but the change was less than while anaesthetised. Consistent with this finding, the aEEG parameters showed age-related differences between awake and anaesthetised states. In all age groups aEEG was greater in the anaesthetised state; the absolute difference was very small in infants and increased with age.

SEF90 did not change with age in the anaesthetised state while there was some modest rise in SEF90 with age in the awake state. There was no SEF90 difference found in the anaesthetised compared to the awake state for children aged between six to 12 months, and paradoxically SEF90 was greater in children younger than six months of age. A reduction in SEF90 of children older than two years of age in response to anaesthetics, is in keeping with adult studies investigating SEF during anaesthesia^{29,30}. Previously Davidson and colleagues²² reported that SEF90 in children younger than two years of age could not discriminate between anaesthetised and emergence states. This current larger study provides support for this finding; as the SEF90 of children younger than two years of age, owing to their predominantly lower awake frequency, either remained the same or conversely increased in response to anaesthetics.

The lack of evidence for a difference in SEF90 between awake and anaesthetised state in infants is consistent with the poor performance, in this age group, of depth monitors such as Bispectral Index that predominantly rely on analysis of the frequency domain. Unlike SEF90, aEEG did show some evidence for a difference between anaesthesia and awake state in infants. The difference was marginal but this finding does suggest further more controlled studies should be done to explore the possibility that aEEG could be used to measure anaesthesia depth in infants. It should be noted that the full complexities of EEG changes that occur during anaesthesia³¹ are not accounted for in this algorithm. At higher doses of some anaesthetics, burst suppression occurs, while others provoke higher frequency beta activity³¹. These changes will not be accounted for in single dimension algorithms such as SEF90 or aEEG. Future investigations will be required to assess age-related changes to burst suppression patterns or beta activation.

For the duration of this study the choice of anaesthetic remained at the anaesthetist's discretion. It is recognised that this introduces a heterogeneity which might reduce the power of this explorative study. A more controlled anaesthetic regimen would be better suited to determine the exact relationship between anaesthesia and EEG at different stages. However, an anaesthesia protocol which prescribes the anaesthetic is more difficult to perform and raises ethical issues if the protocol is not in accordance with what the treating doctor considers is in the child's best interest. Thus, before designing such a study it was decided to perform this exploratory observational study where the anaesthetic was not prescribed, to establish directions for future investigations. There is a possibility that our comparisons between ages may be influenced by factors not controlled for in this study such as use of premedication, varying dose of agents, different agents and varying surgical stimuli. Future studies will need to control for these variables.

In addition, due to the exploratory nature of this study, no sample size calculation was undertaken prior to recruitment. The lack of available research, regarding the EEG of children during anaesthesia, meant that relevant differences in the EEG were not available to complete a power calculation. Thus, there will be uncertainty regarding the true scientific significance of the reported findings. However, this study provides preliminary information that will help to inform future investigation into the EEG of children during anaesthesia.

Another limitation of this study is the asymmetrical filter used by the ReBrim monitor prior to processing EEG processing. This filter strongly attenuates activity below 2 Hz and above 20 Hz²⁶. EEG activity relevant to the monitoring of EEG during anaesthesia may occur outside these ranges such as information in the delta, higher beta³² and gamma³³ frequencies. However, examination of the EEG within the 2 to 20 Hz range reduces artefact contamination and reduces the signal-to-noise ratio³⁴. Future studies will need to establish the clinical relevance of paediatric EEG information outside the 2 to 20 Hz range and overcome the challenges of ensuring EEG data is not contaminated with artefact.

This study also found that during anaesthesia, children younger than four years of age have lower aEEG from forehead regions compared to the parietal recordings, and in older children the forehead SEF90 was significantly higher than parietal recordings. The findings of this study imply that choice of montage is important when choosing potential EEG parameters to measure anaesthesia depth in children. However, the use of three EEG montages is also a limitation of this study. Attempts to obtain larger montage recordings may have led to increasing distress to awake children (entertaining children, and attaching seven sensors, then keeping the sensors in situ while the child was awake was challenging). Much of the awake EEG data was contaminated with artefact and removed by the post hoc filtering. This artefact was particularly evident in the forehead region due to blinking and facial movements. To improve the quality of the awake data providing an area where the children could be quiet with eyes closed may have revealed cleaner EEG data.

CONCLUSION

This exploratory study of a heterogeneous clinical population found that in older children there are clear differences in aEEG and SEF90 between awake and anaesthetised states. In infants the difference in aEEG between awake and anaesthetised is less clear, while SEF90 is an inconsistent discriminator of anaesthetic state. These findings support further investigation of aEEG as a measure of anaesthesia depth in infants.

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